Journal of Plant Nutrition

Broiler Litter as a Sole Nutrient Source for Cotton: Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium Concentrations in Plant Parts

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ABSTRACT

The ability of poultry litter to support plant growth by supplying essential plant nutrients in the absence of other sources of the nutrients has not been studied thoroughly. The objectives of this research were to (1) determine the ability of poultry litter, as the sole nutrient source, to provide macronutrients and support growth of cotton (*Gossypium hirsutum* L.) (2) evaluate the distribution of these nutrients within the different plant parts, and (3) estimate the efficiency with which these nutrients are extracted by cotton. The research was conducted in plastic containers filled with a 2:1 (v/v) sand:vermiculite growing mix under greenhouse conditions. The treatments included broiler litter rates of 0, 30, 60, 90, or 120 g pot^{-1} with or without supplemental Hoagland's nutrient solution. Broiler litter supplied adequate amounts of the macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) and supported normal growth of cotton. Tissue nutrient analysis showed that the concentration of N, P, K, and Mg in the upper mainstem leaves was within published sufficiency ranges for cotton growth. Evaluation of the N distribution indicated that the cotton plant partitions N to reproductive parts when faced with deficiency of this nutrient and favors allocating N to new leaf growth once the requirement for reproductive growth is met. The partitioning of P was similar to that of N but less distinct. Cotton extracted Mg and K with greater efficiency (up to 58%) than the other nutrients and stored these nutrients in older leaves. The extraction efficiency of N ranged between 21% at 120 g pot^{-1} litter and 27% at 30 g pot^{-1} litter. Phosphorus was the most poorly extracted nutrient, with only 16% of the total applied P extracted when 30 g pot^{-1} litter was applied and only 6% extracted at the higher litter rates. This suggests that the same problem of P buildup that has been reported in soils under pasture may also occur when poultry litter is repeatedly applied to the same soil planted to cotton. These results show that broiler litter not only supplied

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enough N but also supplied the four other macronutrients (P, K, Ca, and Mg) in amounts sufficient to support normal cotton growth. This research implies that poultry litter can effectively substitute for several fertilizers to meet crop macronutrient (N, P, K, Ca, and Mg) needs in soils deficient in any or all of these nutrients.

INTRODUCTION

Poultry litter as a fertilizer is used primarily to meet the nitrogen (N) needs and sometimes the phosphorus (P) needs of crops. As a result, the vast majority of poultry litter research has been focused on the management of litter as a source of N and on the dynamics of N (and to some extent, P) in the soil (Sims, 1987; Andrews et al., 1999). Often, the performance of litter as a N source is compared with that of conventional N fertilizers (Wood et al., 1993; Mitchell et al., 1995; Negatu et al., 1996; Glover et al., 1998; Malik and Reddy, 1999).

Traditionally, the total N applied is calculated as the product of the weight of applied litter and the percent total N content of the litter, which is analytically determined. Yield increase due to applied litter and therefore computed litter N is then compared against and equated to the yield increase due to applied conventional fertilizer N. This method of comparison assumes that all the yield increases arise from the N supplied by the litter and not from the litter's other components or beneficial characteristics. Mitchell (1997), for example, credited all of the yield benefit due to broiler litter in a study in Alabama, USA, to the N supplied by the litter, which led the researcher to conclude that "...total N in litter is as effective as N from ammonium nitrate fertilizer...." It is very likely that the yield benefit in this and other research was due to the combined effect of macronutrients, micronutrients, organic matter, and other benefits of the litter, such as disease-suppressing effects.

Analytically, poultry litter is a complete plant food (Collins et al., 1999). However, its ability to support plant growth by supplying essential plant nutrients in the absence of other sources of the nutrients has not been studied thoroughly. The objectives of this research were to (1) determine the ability of poultry litter, as the sole nutrient source, to supply macronutrients needed for optimum cotton growth, (2) evaluate the distribution of these nutrients within the different plant parts, and (3) estimate the efficiency with which these nutrients are extracted by cotton.

MATERIALS AND METHODS

Plant Culture

This study was conducted using 11 L plastic pots filled with ∼11 kg of a 2:1 (v/v) sand:vermiculite growing mix under greenhouse conditions at Mississippi State,

MS. The treatments included broiler litter rates of 0, 30, 60, 90, or 120 g pot^{-1}, with or without supplemental Hoagland's nutrient solution. Water was applied in place of nutrient solution for treatments without supplemental nutrient solution. All treatment combinations were tested using the randomized complete block design with three blocks. The broiler litter was applied to approximately 75% of the final soil volume on December 16, 2002, thoroughly mixed in a separate plastic container, and placed back in the pots. This mixture was topped with a layer about 3 cm deep of the same growing mix, using the remaining 25% mix without the litter to help reduce volatilization loss of N. Each pot was then provided with enough water to thoroughly wet the entire growing mix and allowed to stand for 21 days before planting to help reduce seedling damage due to initial surge of ammonia (Siegel et al., 1975). The litter as applied to the growing mix contained 29.3 g total N kg^{-1}, 16.6 g P kg^{-1}, 27.6 g K kg^{-1} (potassium), 27.4 g Ca kg^{-1} (calcium), 5.78 g Mg kg^{-1} (magnesium), 684 mg Fe kg^{-1} (iron), 424 mg Zn kg^{-1} (zinc), 522 mg Mn kg^{-1} (manganese), and 556 mg Cu kg^{-1} (copper).

Five cotton (cv. 'Stoneville 474') seeds were planted in each pot on January 6, 2003 and thinned to two plants per pot after seedlings were established. Adequate water was applied to each pot to meet the water needs of plants throughout the growing period. Drainage was prevented by applying just enough water to wet the soil volume. As a precaution, a clear plastic container was placed under each pot to collect drainage in case water applied exceeded the holding capacity of the growing mix.

Measurements

Plants were harvested 92 d after planting on April 8, 2003. At this stage all plants, other than the ones that received 0 g litter pot^{-1}, had produced at least some squares and flowers. Nodes were counted and plant heights measured as the distance between the cotyledonary node and the last node on the mainstem. All plants were lightly rinsed with a fine mist of tap water, cut at soil level, and partitioned into leaves (blades and petioles), stems (branch and mainstem), and fruits. Leaves were further separated into upper, middle, and lower mainstem leaves and branch leaves. After taking mainstem leaves from the upper three nodes, the remainder mainstem leaves were divided equally into lower and middle nodes. All leaves from branches were placed in a separate group. Control plants (0 g pot^{-1} litter) produced only one or two true leaves, which were placed into one group as middle mainstem leaves. Roots of all plants were gently separated from the growing mix and thoroughly washed with tap water to remove adhering sand, vermiculite, or litter. Plant parts were dried in a forced-air oven at 80°C to a constant weight, weighed, ground to pass a 1 mm sieve, and analyzed for nutrient concentration.

Nutrient Analysis

Total N concentration in the different plant parts was determined by an automated dry combustion method using a ThermoQuest (CE Elantec Inc., Lakewood, NJ) C/N analyzer (Horneck and Miller, 1998). Concentrations of P, K, Ca, and Mg in the plant parts were determined by inductively coupled plasma (ICP) emission spectroscopy (Donohue and Aho, 1992). Approximately 0.2 g dried and ground samples were ashed in a muffle furnace at $500°C$ for 4 h. The ash was digested by adding 1.0 mL 6 M HCl for 1 h and 40 mL of a double-acid solution of 0.0125 M H_2SO_4 and 0.05 M HCl for an additional 1 h. The digested solution was then filtered using a 2 V Whatman filter paper and analyzed for concentration of the various elements using inductively coupled argon plasma emission spectroscopy (Thermo Jarrell-Ash Model 1000, Franklin, MA). Plants that did not receive litter had an adequate number of stems for analysis by both ICP and C/N analyzer. The leaf and root tissues from these plants, however, were only sufficient for analysis with the C/N analyzer. These plants did not produce reproductive parts.

Nutrient accumulation in each plant part was calculated as the product of concentration and dry weight of each plant part. Total nutrient extraction by plants in each pot was determined as the sum of nutrients accumulated in leaves, stems, roots, and reproductive parts. Total nutrient extraction as percent of total applied was considered as the efficiency by which cotton extracted these nutrients from the growing mix. All data were subjected to analysis of variance on SAS.

RESULTS AND DISCUSSION

Plant Growth

Broiler litter seemed to supply adequate amounts of all essential nutrients and support normal growth of cotton in the absence of any other source of nutrients. Plants showed little or no growth after emergence and initial production of about one or two very small true leaves when litter or supplemental nutrient solution was not applied. These plants formed not more than two mainstem nodes and accumulated only 0.74 g pot^{-1} total dry matter 92 d after planting, showing that the growing mix was near-inert (Table 1). Applying 30 g pot^{-1} litter to the growing mix without supplemental nutrient solution resulted in a discrete increase in plant growth. Additional litter beyond 30 g pot^{-1} increased dry matter of the different plant parts to varying extents. Plant height and root dry weight were not significantly affected by any of the litter rates $\geq$30 g pot^{-1}. All other growth measurements were significantly increased by additional litter beyond 30 g pot^{-1} but not beyond 60 g pot^{-1}.

Table 1

Growth of greenhouse-grown cotton supplied with broiler litter as the sole nutrient source or supplemented with a Hoagland nutrient solution

Applied broiler litter	Plant height	Mainstem nodes	Dry weight				
			Root	Stem	Leaf	Repro	Total
g pot^{-1}	m	no.	g pot^{-1}				
Without Supplemental Nutrient Solution							
0	0.01b	1.2c	0.3b	0.1c	0.3c	0.0b	0.7c
30	0.39a	9.2b	5.2a	8.2b	11.3b	0.9b	25.6b
60	0.48a	12.0a	5.7a	10.4ab	13.7a	3.2a	32.9a
90	0.42a	12.2a	6.3a	10.8a	15.0a	3.3a	35.5a
120	0.39a	11.3a	6.4a	10.4ab	14.0a	4.2a	34.9a
With Supplemental Nutrient Solution							
0	0.44a	10.5b	4.7b	9.1ab	12.8a	1.0b	27.6b
30	0.43a	11.8a	7.0a	10.8a	14.2a	3.2a	35.1b
60	0.39a	11.7ab	7.3a	10.8a	14.3a	4.5a	36.8a
90	0.42a	12.5a	6.3ab	9.9ab	14.1a	3.2a	33.5ab
120	0.41a	12.0a	6.1ab	8.5b	12.6a	3.6a	30.8ab

Values designated with the same letter within a column and Hoagland solution are not significantly different at $P \leq 0.05$.

Supplementing litter with Hoagland's nutrient solution increased plant growth only when no litter was applied and, to some degree, when 30 g pot^{-1} litter was applied (Table 1). Supplemental nutrient solution did not affect plant growth when applied litter was ≥ 60 g pot^{-1}. This suggests litter at ≥ 60 g pot^{-1} supplied adequate nutrients to support plant growth.

Nutrient Sufficiency

In addition to plant growth, tissue nutrient analysis showed that broiler litter supplied sufficient amounts of N, P, K, and Mg for cotton growth. The concentration of P, K, and Mg in whole leaves from the upper one-third nodes of plants that received litter as the sole nutrient source, regardless of the rate, fell within published sufficiency ranges (Mitchell and Baker, 2000) (Table 2). Litter as the sole nutrient source also resulted in sufficient concentrations of N, but it was necessary to apply 120 g pot^{-1} litter to bring the N concentration to within the sufficiency range. All other litter rates resulted in leaf N concentration below the critical level of 30 g kg^{-1}. Although the litter supplied as much Ca as K, the concentration of Ca in the upper leaves was below the sufficiency range,

Table 2

Nutrient concentration in the upper whole leaves of greenhouse-grown cotton that received broiler litter with or without supplemental nutrient solution compared with published sufficiency ranges (Mitchell and Baker, 2000)

| Nutrient	Applied broiler litter, g pot $^{-1}$					Sufficiency range
	0	30	60	90	120	
Concentration, g kg $^{-1}$						
Without Supplemental Nutrient Solution						
N	—	12.4	21.8	26.6	33.2	30–45
P	—	4.0	4.2	4.5	4.9	1.5–6
K	—	12.3	18.1	20.5	25.3	7.5–25
Ca	—	12.4	11.8	11.4	13.3	20–40
Mg	—	4.1	4.4	4.6	5.5	3–9
With Supplemental Nutrient Solution						
N	41.3	41.3	40.6	42.3	46.4	30–45
P	3.6	3.4	3.2	3.9	4.5	1.5–6
K	29.1	31.7	32.9	32.6	34.5	7.5–25
Ca	18.9	18.0	21.7	19.2	22.9	20–40
Mg	6.5	6.4	6.8	6.9	7.8	3–9

suggesting that the plants did not receive adequate amounts of Ca from litter regardless of the rate.

These results show that litter can supply N as well as the other macronutrients, with the exception of Ca, in amounts sufficient to support normal cotton growth. However, supplementing litter with Hoagland's nutrient solution, relative to litter as a sole nutrient source, increased concentrations of N, K, Ca, and Mg in the upper mainstem leaves (Table 2). These increases, which occurred at all litter rates, suggest that plants accumulate these nutrients in leaves as "luxury consumption," or that litter supplied the nutrients in marginal amounts.

Nutrient Distribution

Nitrogen

Tissue N concentration differed substantially in the various plant parts. Overall, the order of N concentration in the different plant parts when litter was the sole nutrient source was as follows: reproductive parts > upper mainstem leaves = branch leaves > middle mainstem leaves > lower mainstem leaves > roots > stems (Figure 1). When litter was the sole nutrient source, N concentration was
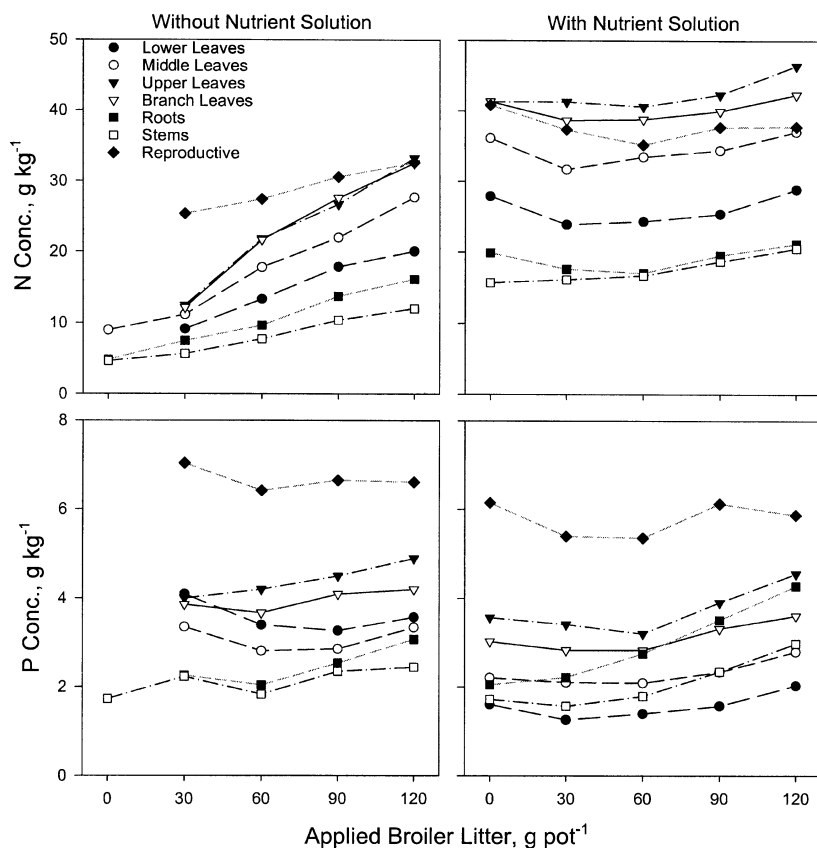
Figure 1. Concentration of N and P in different plant parts of cotton fertilized with different rates of broiler litter with or without supplemental Hoagland's nutrient solution in a sand: vermiculite growing mix.

about the same ($\sim$33 g kg^{-1}) in reproductive parts, upper mainstem leaves, and branch leaves of plants that received 120 g litter pot^{-1}. The difference in N concentration between reproductive parts and upper mainstem leaves or branch leaves was largest in plants that received 30 g litter pot^{-1}. This difference became smaller as applied litter increased to 120 g pot^{-1}. Nitrogen concentration in reproductive parts was nearly twice that in either mainstem leaves or branch leaves when only 30 g pot^{-1} of litter was applied. This suggests that the 30 g pot^{-1} litter did not supply adequate N to support the growth of all plant parts and that plants favored partitioning N to reproductive parts as a priority when faced with N deficiency. This is a commonly reported response of plants to N deficiency. The difference in N concentration among the different plant parts other than reproductive parts was largest at 120 g pot^{-1} than at the 30 g pot^{-1}

litter rate. The sharper increase of N concentration with increasing litter rate in younger leaves (upper mainstem leaves and branch leaves) than in any other plant part other than the reproductive parts shows that the cotton plant partitions N to the production of new leaves as well as reproductive parts when N is not limited. Nitrogen is partitioned to reproductive parts at the expense of new leaf formation when available in limited amounts.

Relative to litter alone, supplemental Hoagland's nutrient solution increased N concentration in all plant parts (Figure 1). The largest increase, 232%, was in upper leaves at the 30 g pot^{-1} litter treatment and the smallest increase, only 16%, was in reproductive parts at the 120 g pot^{-1} litter treatment. Nitrogen concentration in upper leaves did not exceed the N concentration in reproductive parts at any litter rate when litter was not supplemented with nutrient solution (Figure 1). However, when litter was supplemented with nutrient solution, N concentration in upper leaves and branch leaves exceeded N concentration in reproductive parts at all litter rates except the 0 g pot^{-1} litter treatment. This further demonstrates that N is partitioned to new leaves once the requirement for reproductive growth is met.

Phosphorus

Differences in P concentration among the various plant parts were similar at high or low litter rates, with or without supplemental nutrient solution (Figure 1). Concentration of P was far greater in reproductive parts than in any other plant part at any of the litter rates. The concentration of P averaged across all litter rates with no supplemental nutrient solution was 6.7 g kg^{-1} in reproductive parts compared with only 4.4 g kg^{-1} in the upper mainstem leaves. All other plant parts had a lower concentration of P than upper mainstem leaves. Unlike N concentration, P concentration showed only small increases in only some of the plant parts with increasing litter rate. The sharpest increase in P concentration with increasing litter rate was in roots and upper mainstem leaves. Phosphorus concentration increased by 36% in roots and by 22% in upper leaves when applied litter was increased from 30 to 120 g pot^{-1}. It increased by <10% in stems and branch leaves, remained virtually unchanged in middle mainstem leaves, and decreased by up to 12% in lower mainstem leaves and reproductive parts when applied litter was increased from 30 to 120 g pot^{-1}. The larger increase in P concentration in roots than in any other plant part may support some claims that P enhances root growth. These results indicate that, unlike N, P does not seem to be absorbed by cotton as a luxury consumption.

Supplemental nutrient solution depressed P concentrations in all plant parts but roots (Figure 1). The depression was largest in lower leaves at any of the litter rates and across all plant parts at the 30 g pot^{-1} litter rate. When averaged across litter rates ≥30 g pot^{-1}, the decrease in P concentration due to supplemental nutrient solution was 56% in lower leaves, 25% in middle leaves, 14% in upper leaves, 21% in branch leaves, 15% in reproductive parts, and

only 2% in stems. Average P concentration in roots increased by 29%. When averaged across all plant parts including roots, supplemental nutrient solution decreased P concentration by 30%, 20%, 12%, and 7% at the 30, 60, 90, and 120 g pot^{-1} litter treatments, respectively. The decreasing effect of supplemental nutrient solution on tissue P concentration may be an indication that P from litter that mineralized and became plant available reacted with the metal nutrients supplied by the nutrient solution, precipitated as an insoluble compound, and became unavailable for plant uptake. This effect was most extensive in lower leaves, probably because of remobilization of P from lower leaves to other plant parts.

Potassium

Unlike N and P concentration, K concentration was greatest in the oldest mainstem leaves of plants that received litter as the sole nutrient source (Figure 2). Concentration of K in the lower mainstem leaves averaged across all litter rates ≥30 g pot^{-1} was 32.9 g kg^{-1} compared with only 19.1 g kg^{-1} in the upper leaves. Considering that K is a highly mobile nutrient within the plant and the most abundant cation in the cell cytoplasm (Marschner, 1986), the large differences in K concentration between the upper and lower leaves may be an indication that older leaves store K in compartments such as cell vacuoles more than do younger leaves. Potassium concentration in branch leaves, in mainstem leaves regardless of position, and in stems increased with increasing rate of applied litter between 30 and 120 g pot^{-1}, but the concentration of this nutrient remained almost constant in reproductive parts, at 24.6 g kg^{-1}, or decreased from 27.9 to 21.5 g kg^{-1} in roots with increasing rates of applied litter.

Supplemental Hoagland nutrient solution increased K concentration in all leaves, with the largest increase of up to 165% occurring at the 30 g pot^{-1} litter rate; the increase became progressively smaller with higher litter rate. Nutrient solution increased K concentration in stems by 29% when averaged across all litter rates ≥30 g pot^{-1}. It decreased K concentration in roots by 24% at 30 g pot^{-1} litter and by 17% at 60 g pot^{-1} litter, had no affect at 90 g pot^{-1}, and increased K concentration by 34% at 120 g pot^{-1} litter. Potassium concentration in reproductive parts was not affected by either nutrient solution or litter rate, which shows that reproductive parts do not accumulate K beyond what is necessary for growth.

Calcium

Calcium was one of the nutrients most distinctly stratified in the different vegetative plant parts (Figure 2) regardless of the litter rate or supplemental nutrient solution. Variations in Ca concentration in each vegetative plant part averaged across litter rates occurred in the following order: lower leaves > middle leaves > upper leaves = branch leaves > roots = stems. Lower mainstem leaves
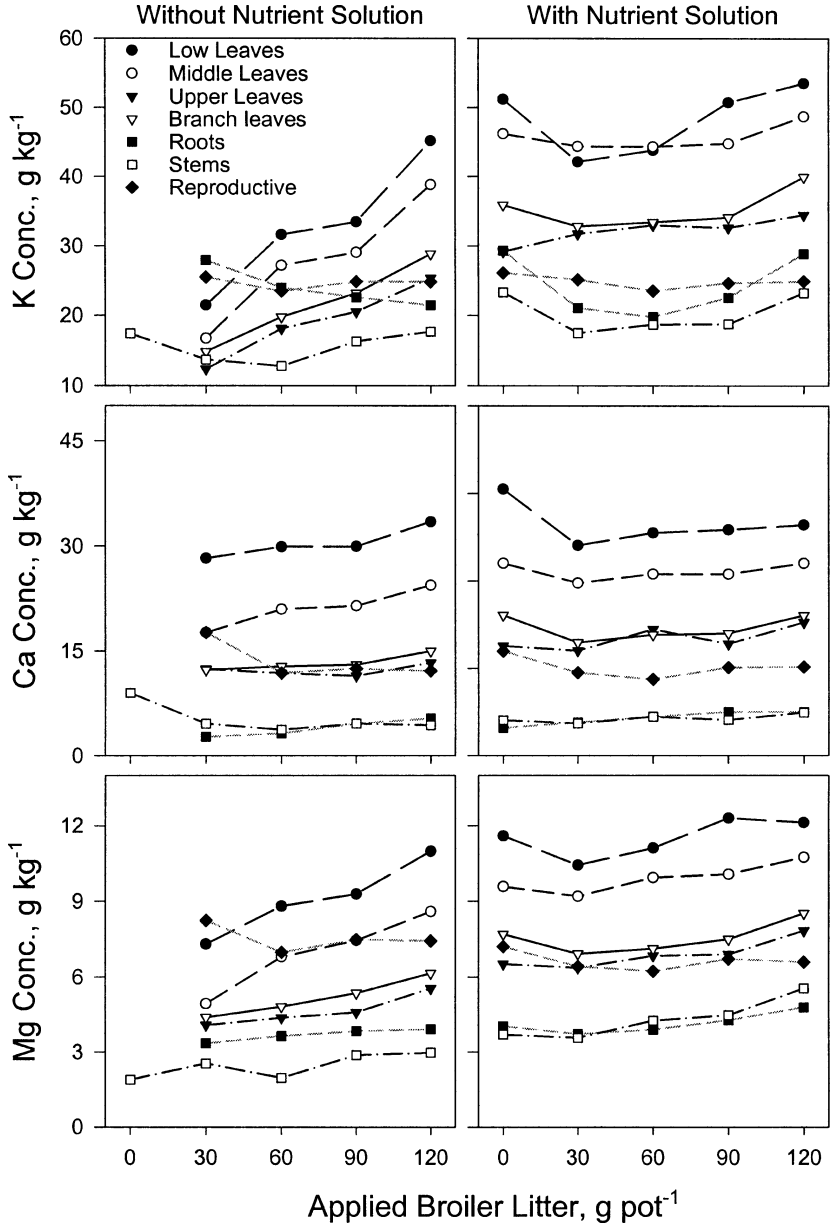
Figure 2. Concentration of K, Ca, and Mg in different plant parts of cotton fertilized with different rates of broiler litter with or without supplemental Hoagland's nutrient solution in a sand: vermiculite growing mix.

of plants that did not receive supplemental nutrient solution had an average Ca concentration of 30.4 g kg^{-1} compared with <13.5 g kg^{-1} in upper leaves, branch leaves, or reproductive parts. The average Ca concentration in roots and stems did not exceed 4.3 g kg^{-1} at any litter rate. The greater concentration of Ca in older leaves than in newer leaves when litter was the sole nutrient source may have occurred because plant-available Ca in the growing mix was depleted during the early growth stages and stored in the older leaves. This nutrient is not redistributed from older leaves to newer leaves, which also probably contributed to the discrepancy in leaf Ca concentrations.

The change in tissue Ca concentration with increasing litter rate was relatively small in all plant parts. The increase in Ca concentration when litter rate increased between 30 and 120 g pot^{-1} was largest in roots, although root Ca concentration was the lowest among all plant parts. Calcium concentration increased by 97% in roots, but by only 7% to 39% in leaves, remained unchanged in stems, and decreased by 31% in reproductive parts when applied litter increased from 30 to 120 g pot^{-1} without supplemental nutrient solution. The increase in Ca concentration with increasing litter rate in the upper leaves was only 7%, which suggests that Ca supplied by litter probably was not limiting. However, it is also possible that plant-available Ca was exhausted during the early growth stages. This is suggested by the much greater concentration of Ca in older leaves and a greater increase of Ca concentration with increasing applied litter rate in older leaves than in newer ones.

Supplementing litter with nutrient solution increased Ca concentration in all plant parts at all litter rates. The increase averaged across the litter rates ranged from as small as 7% in reproductive parts to as large as 74% in roots.

Magnesium

The concentration of Mg in the different plant parts showed similar stratification as the concentration of Ca (Figure 2). Variations in Mg concentrations in vegetative plant parts averaged across litter rates occurred in the following order: lower leaves > middle leaves > branch leaves > upper leaves > roots > stems. Lower mainstem leaves of plants that did not receive supplemental nutrient solution had an average Mg concentration of 9.1 g kg^{-1} compared with <5.2 g kg^{-1} in upper or branch leaves. The corresponding Mg concentrations were 7.5 g kg^{-1} in reproductive parts, 3.7 g kg^{-1} in roots, and 2.6 g kg^{-1} in stems.

Magnesium concentration changed with increasing applied litter in the same way as K and Ca concentration. Magnesium concentration increased by 9.9% to 40.7% in roots and leaves, remained nearly unchanged in stems, and decreased by 8.5% in reproductive parts when applied litter as the sole nutrient source was increased from 30 to 120 g pot^{-1}. Both Mg and K are stored as inorganic salts, primarily in cell vacuoles, when the supply exceeds the minimum necessary for growth (Marschner, 1986). The greater concentrations

of Mg and K in older leaves than in newer leaves may be an indication that the litter supplied both nutrients in excess of the minimum necessary for growth and that the excess Mg and K were stored as described. Cells of older leaves are expected to have smaller cytoplasm and larger and better-developed cell vacuoles than cells of newer leaves, and should therefore provide greater storage space.

Supplementing litter with nutrient solution increased Mg concentration much as it did Ca concentration. The increases, averaged across the litter rates, ranged from as small as 13% in roots to as large as 72% in stems. Unlike Ca concentration, Mg concentration in reproductive parts was reduced by an average of 14% under supplemental nutrient solution.
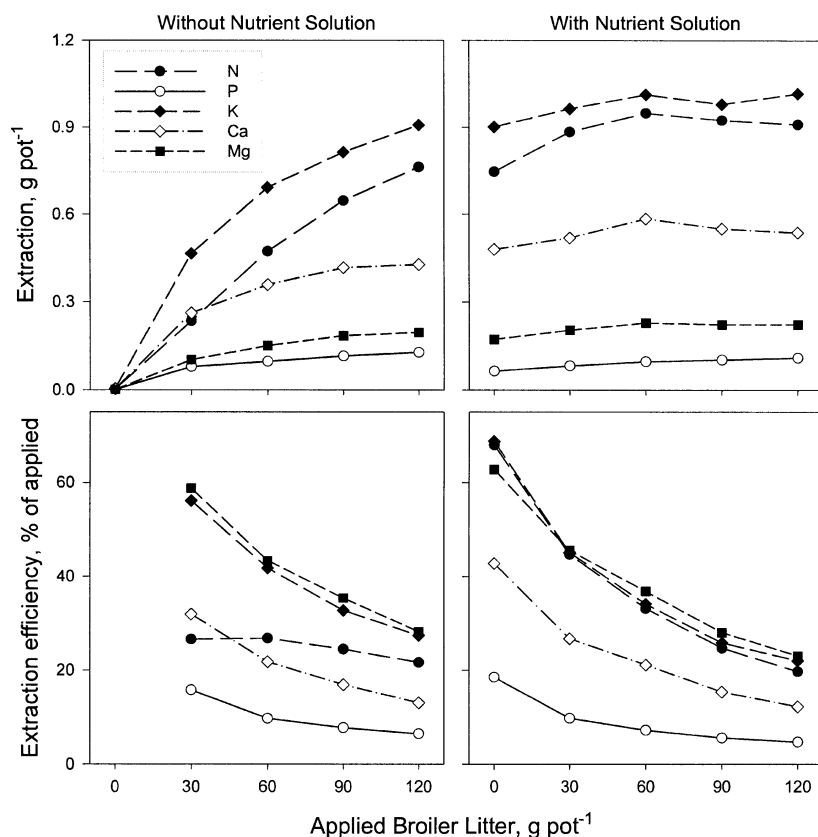
Nutrient Extraction

Total Extraction

When no supplemental nutrient solution was added, extraction of nutrients from the growing mix increased with increasing rates of applied litter, but the rates of increase differed among the different nutrients (Figure 3). The increase of total K and N extraction with increasing rates of applied litter was greater than the increase of extraction of the other nutrients. When available in abundance, K can apparently be luxuriously consumed (Marschner, 1986) and accumulate in plant tissues. However, this may not result in excessive growth, as it often occurs with luxury consumption of N. At the higher litter rates in this study, the plants seemed to allocate N to upper leaves and reproductive parts (Figure 1), suggesting that N is used for new growth when available in abundance. Unlike excess N, excess K seemed to be stored in older leaves with sufficient concentration in younger leaves for growth (Figure 2). The rate of increase of P and Mg extraction was very small compared to that of the other nutrients. Calcium extraction was intermediate. The increase of total nutrient extraction with increasing applied litter when supplemented with nutrition solution was much smaller than when litter was not supplemented (Figure 3).

Extraction Efficiency

Cotton extracted litter Mg and K with greater efficiency than it did the other nutrients (Figure 3). This was particularly true at the lowest rate of applied litter. Plants that received 30 g pot^{-1} litter extracted 58% of the total applied Mg and 56% of the total applied K when harvested around the early boll growing stage. This efficiency dropped to 28% for Mg and 27% for K when applied litter was increased to 120 g pot^{-1}. Extraction efficiency of Ca decreased from a high of 32% at 30 g pot^{-1} applied litter to 13% at 120 g pot^{-1} litter.

Figure 3. Ability of cotton to extract N, P, K, Ca, and Mg supplied by broiler litter with or without supplemental Hoagland's nutrient solution in a sand: vermiculite growing mix.

The extraction efficiency of N ranged between 21% at the highest rate of litter application and 27% at the lowest. This is substantially less than the 36% recovery efficiency demonstrated by field-grown corn (*Zea mays* L.) as reported by Sims (1987). However, the cotton in our study was not grown to maturity and therefore much more N recovery would have occurred had the cotton been allowed to reach this stage. The decrease of nutrient extraction efficiency with increasing rate of applied litter in our study was by far smaller for N than for the other nutrients. The smaller decrease in N extraction efficiency with increasing litter rate demonstrates that cotton continues to extract N from the soil as it becomes plant-available. This probably leads to the commonly observed excess vegetative growth associated with excess N application.

Phosphorus was the most poorly extracted nutrient, with only 16% of the total applied P being extracted when 30 g pot^{-1} litter was applied (Figure 3).

The extraction efficiency was as low as 6% with higher litter rates. However, since the greatest demand for P is for seed growth (Bassett et al., 1970; Halevy, 1976), we suspect the extraction efficiency would have been greater had the plants been harvested later around maturity.

Supplemental nutrient solution decreased extraction efficiency of all nutrients but N. When averaged across litter rates, supplemental nutrient solution decreased extraction efficiency of P by 31%, K by 20%, Ca by 10%, and Mg by 19% and increased that of N by an average of 23% over litter alone.

These results suggest that cotton can trap and hold a good fraction of litter N, K, and Mg in its different plant parts. Although all plant parts are not removed from the soil away to a different location for disposal, the ability of the cotton plant to extract these nutrients from the soil can be considered as a temporarily safe storage of these nutrients. The ability of cotton plants to provide a temporary storage for P was very poor, implying that the same problem of P buildup previously reported in pastures may occur when poultry litter is repeatedly applied to the same soil under cotton.

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